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Supporting the Future Air Traffic Control Projection Process

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ABSTRACT

In air traffic control, projecting what the air traffic situation will be over the next 30 seconds to 30 minutes is a key process in identifying conflicts that may arise so that evasive action can be taken upon discovery of these conflicts. A series of field visits in the Boston and New York terminal radar approach control (TRACON) facilities and in the oceanic air traffic control facilities in New York and Reykjavik, Iceland were conducted to investigate the projection process in two different ATC domains. The results from the site visits suggest that two types of projection are currently used in ATC tasks, depending on the type of separation minima and/or traffic restriction and information display used by the controller. As technologies improve and procedures change, care should be taken by designers to support projection through displays, automation, and procedures. It is critical to prevent time/space mismatches between interfaces and restrictions. Existing structure in traffic dynamics could be utilized to provide controllers with useful behavioral models on which to build projections. Subtle structure that the controllers are unable to internalize could be incorporated into an ATC projection aid.

KEYWORDS

projection, situation awareness, air traffic control, information requirements, decision support

INTRODUCTION

Projection is one of the three critical stages that contribute to an air traffic controller's situation awareness (Endsley, 2000). A controller must be able to project current aircraft states in order to identify conflicts so that they can be resolved before they occur. However, it is unclear how controllers perform this critical task in the current air traffic environment. The difficulty in understanding current projection limitations complicates the establishment of projection requirements for air traffic systems that are being designed for the future.

The air traffic control system is at a point of transition that could potentially change the controller's projection task. As the demand for more fuel-efficient and environment-friendly procedures increases, there is a need for increased flexibility currently required by the FAA and other air traffic authorities. It is critical to determine the role of the existing structure in the airspace and procedures in the controller's projection task before it is removed or changed.

One example of a procedure increasing route flexibility is the constant deceleration approach procedures that reduce noise pollution over cities, but these procedures also require the aircraft to follow a deceleration profile determined by the aircraft's automation rather than a profile cleared by the air traffic controller (Clarke & Hansman, 1997). An example of a procedure increasing lateral route flexibility is the free-routing procedure being implemented over the oceans that cut down both flight time and fuel usage on overseas flights. These free routing procedures require flexibility from strict tracks structures used to ensure adequate separation over poorly-surveilled oceanic environments (NAT-IMG, 1999).

This paper investigates how the air traffic control projection is currently performed, including the role of structure, and discusses the limitations of human projection. Suggestions are provided to support these human projection limitations in the future.

METHOD

Preliminary models of controller cognition were produced, based on a more general ATC cognitive model proposed in Reynolds, et al. (2002) and modified using job/task analyses for TRACON and oceanic air traffic controllers (Endsley & Jones,

1995; Lenorovitz, Schaghaghi, Felbinger, & Tyler, 2000).

Site visits were then performed at terminal radar approach control (TRACON) facilities and at oceanic facilities to revise the cognitive models created and to specifically probe the projection process. TRACON site visits included four 4-hour visits to Boston and two 4-hour visits to New York. Oceanic site visits included four 4-hour visits to New York and five 4-hour visits to Reykjavik, Iceland.

The site visits consisted of focused interviews with controllers and training personnel as well as observations of live operations. Specific interview questions were created to elicit how the projection was accomplished under different operational circumstances (e.g., "How do you determine if two aircraft will be separated at a particular crossing point?" and "How do you determine if an aircraft will meet the 15 minutes-in-trail restriction?")

COGNITIVE MODELS

Cognitive models based on a conflict projection task were created for the TRACON and oceanic air traffic controllers, which was developed These models incorporate the Situation Awareness concept presented by Endsley (2000) and the decision processes presented by Pawlak (1996). These models were then evaluated against and modified based on actual conflict projection tasks verbally explained by the air traffic controllers.

TRACON Environment

To consider the TRACON projection process, it is useful to discuss the process in terms of a particular projection example. In the final approach control sector, the controller must descend aircraft from the entry point of the sector to the final approach altitude while directing the aircraft to capture the ILS beam on an instrument approach. The majority of traffic in this sector are in transition both laterally and vertically. Precise commands are required of the controller to direct aircraft to the physical constraint of the ILS beam, and there are stringent requirements on the communication and surveillance systems within the TRACON to allow the controller to ensure the 3nm lateral separation requirement between aircraft is maintained.

Figure 1 depicts an example of an air traffic control cognitive projection model for TRACON controllers. In this model, information is fed into the controller through **Perception**, primarily through the radar screen and the VHF radio communication. This information is then **Comprehended** in relation to the goal-relevant tasks of the controller.

The controller then **Projects** the aircraft into the future, using information about the aircraft's current position, intended trajectory, and the point of interest to which the projection is to be made. This information is fed into the working mental model of the aircraft. The **Working Mental Model** is created based on the expected behavior of the aircraft given the attributes observed in the environment and the behaviors that the controller associates with those attributes. Information about behaviors associated with attributes is stored in the **Knowledge Base** of the controller. The projection process results in a estimation of future spatial position on the radar screen relative to another aircraft due to the primary task of maintaining minimum separation requirements between aircraft.

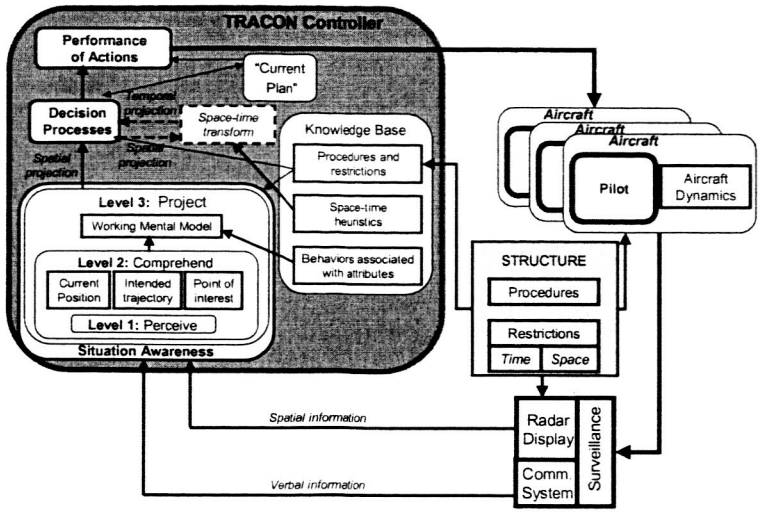

Figure 1: Example model of TRACON projection process.

Because the TRACON environment requires precise projection and control, detailed transitional behavior models are required to make adequate projections for the controller's task. For example, controllers developed discretizations among aircraft vertical transition behavior based upon whether the aircraft is a propeller aircraft, a new jet, or an old jet. Observed pilot behavior, wind information, airline information and equipage information can also provide observable attributes on which to base the working mental model.

The projection resulting from the Situation Awareness component of the controller's cognition is then fed into the Decision Processes. The **Decision Processes** are monitor, evaluate, and plan functions.

Metering can be used in the TRACON environment, and this traffic initiative imposes a minutes-in-trail requirement upon longitudinal separation between aircraft rather than the usual miles-in-trail separation. Because of the natural mapping of spatial separation requirements to surveillance by the radar display, TRACON controllers will often project the separation in terms of spatial distance (e.g., 5 nm) and then convert the distance to a time through a mental heuristic (e.g., 5nm=3 minutes).

Oceanic Environment

The oceanic environment is a significantly different ATC environment from the TRACON. Radar coverage is scarce over the oceans, requiring aircraft to provide current positions over voice channels. A communication relay service is used to communicate aircraft position and clearances to and from the aircraft on high frequency (HF) due to the lack of very high frequency (VHF) coverage over the oceans. Due to the difficulties in surveillance and the third-party involved in communications with the aircraft, the oceanic controllers are unable to make the precise projections and control commands that TRACON controllers are able to make. The separation requirements reflect this difficulty—the average separation requirements over the oceans are 50-100 nm laterally and 1000-2000 ft vertically. In the North Atlantic oceanic airspace, the lateral aircraft routes are structured to maintain this minimum lateral separation and there is little deviation from these preferred "tracks."

Because of the communication and surveillance constraints and the tracks structure, oceanic controller projection over the North Atlantic is a significantly more procedural task. For example, before an aircraft enters a Reykjavik oceanic sector, its flight strip appears in the top area of the electronic flight strip bay depicted in Figure 2. The oceanic controller then drags the flight strip to the altitude grouping at which the aircraft is flying. All of the flight strips are grouped initially by cleared altitudes in the Reykjavik facility.

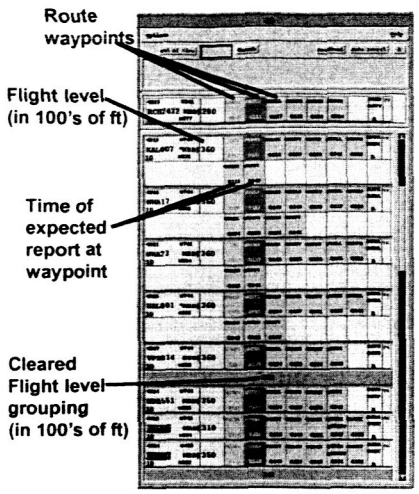

Figure 2: Reykjavik electronic oceanic flight strip bay.

If any other aircraft will be flying at the same flight level, the oceanic controller then determines whether there is a point of intersection along the aircraft routes. Horizontally along each flight strip is a series of waypoints that comprises the route of the aircraft. To determine if there is a point of intersection, these waypoints are scanned for matches with other aircraft in the flight level.

If there is an intersecting point along the route, the controller then compares the estimated time at which each aircraft will be reporting that waypoint. If there is adequate time separation at this point, then the aircraft are considered "separated". If there is not enough time, the flight strip of the entering aircraft is electronically "flagged", and upon entry, the controller will issue a clearance resolving the conflict once the aircraft enters his or her airspace.

The structured nature of the oceanic airspace allows the oceanic controller to use a procedural projection task. An example of a cognitive model for the oceanic controller is shown in Figure 3. This procedural projection has also likely evolved to meet oceanic separation requirements, which are primarily in nautical miles laterally but in minutes longitudinally. A similar procedural projection is

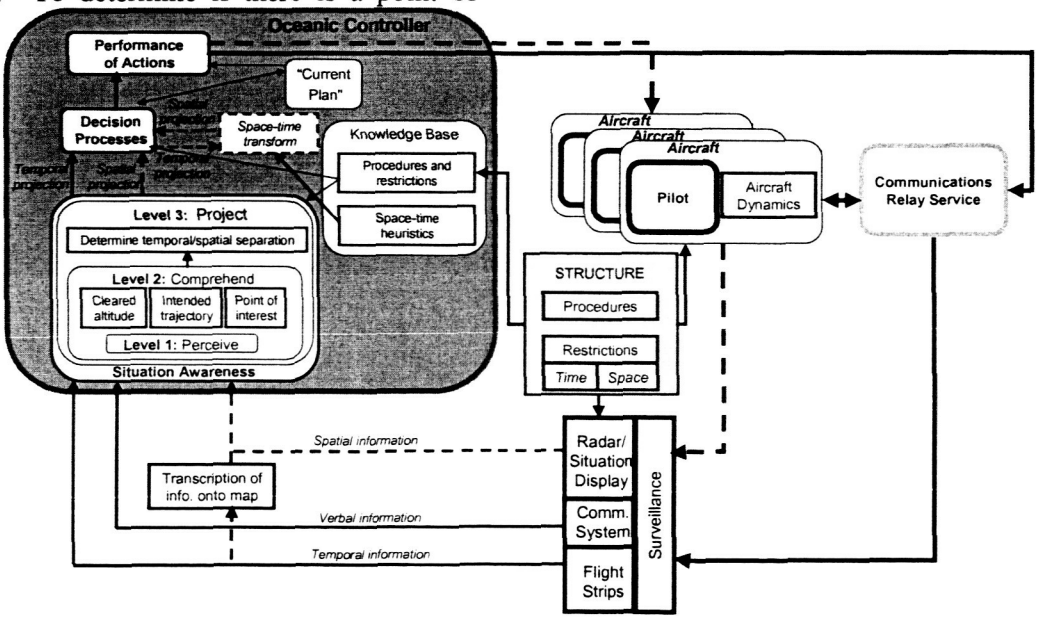

Figure 3: Example of the oceanic air traffic control projection process.

followed in the New York facility, however since the New York facility uses paper flight strips, a different matrix layout is used. Figure 4 is a schematic of the New York flight strip layout, in which the strips are primarily grouped in terms of their reporting points, then within these reporting points, by time reporting that waypoint, then within these times, by altitude.

In the cases in which lateral separation in nautical miles is required, New York oceanic controllers are trained to perform the projection task using a grease board map of the airspace. They plot the current location of the aircraft and the aircraft routes to determine how much separation is required. This transcription transfers information received from the flight strips and voice information updates into a spatial format represented in Figure 3.

A spatial display of the estimated locations of the aircraft based on position reports is being integrated at both New York and Reykjavik facilities, which the controllers have reported to be useful for "gaining awareness of the traffic situation" on a handoff and in the cases in which aircraft are required to be separated by nautical miles. It appears that when separation in nautical miles is required, a spatial display of the information is more often used, while the longitudinal separation requirements in minutes is easily accomplished through a flight strip matrix display of information. However, the controllers are currently not allowed to use the spatial displays for separation purposes, so the spatial displays are automatically relegated secondary to the flight strips regardless of the usefulness.

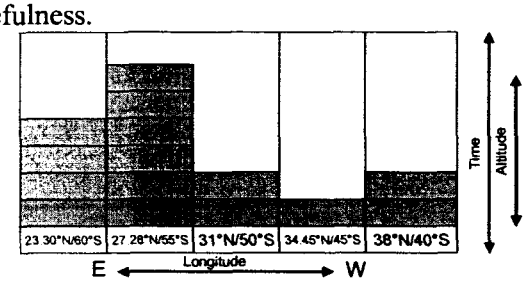

Figure 4: Example of flight strip arrangement in a New York Center oceanic sector mimicking the structure present in the actual environment.

DISCUSSION

Two examples of air traffic control projection were discussed: TRACON spatial-based projection and oceanic time-based projection. Whether time or spatial projection was used depended on the type of separation restriction used (minutes or miles) and the way in which the information was displayed (spatial display or flight strip).

Level of communication/surveillance performance (VHF & radar/HF & non-radar) influenced the precision required of the projection. If precise projections were required (as in the TRACON final approach example), functional behavioral discretizations were created to provide the controller with reliable estimations of future aircraft behavior.

When designing the future air traffic control system to better support the air traffic controller's projection process, the following ATC elements must be considered:

Displays

Information displays in the future must maintain consistency with separation restrictions in the way information is presented. By correcting the mismatch between information perceived and the type of projection needed for decision making processes, the "space-time transform" and the "information transcription onto map" from Figures 1 and 3 will no longer be required making the controller's work more efficient.

The mismatch between separation requirements will become more of an issue as time-based metering is implemented in en route centers & TRACONs across the U.S. due to its throughput efficiency. Time-based information support tools such as NASA's Traffic Management Advisor (TMA) would provide a general awareness of the time dimension that currently does not exist in many TRACONs using metering procedures.

In the oceanic environment, the spatial display will be integrated into the procedures for use during separation, therefore a time/space mismatch is inevitable with the controllers using the spatial display with time-based restrictions. Either support should be provided for the time restrictions similar to a TMA format or the flight strips would need to be better integrated for use with the spatial display.

Effective interfaces for the projection task should also reflect the structure present in the environment. The horizontal waypoint boxes of the flight strip mirrored the east-west position report points of the North Atlantic tracks in the Reykjavik example. By mimicking the structure in the actual environment, a natural bridge was created for controller to follow the situation.

Once the behavioral discretizations used in the controller's projection task are identified, the attributes allowing the controllers to discriminate between behaviors should be made visible on the display. If these behavioral discretizations are means for the controller to generate reliable and useful projections of the situation, the interface should support this cognitive function.

Automation

It is possible that by integrating flexibility into the air traffic system the controller may not be able to adequately internalize the behavioral implications of the existing air traffic structure. Automated projection aids may allow the controller to take advantage of subtle structural consistencies in air

traffic behavior to better project the traffic into the future.

For example, the Converging Runway Display Aid (CRDA) used by some domestic air traffic facilities within the U. S. is a tool that automatically projects a "ghost" aircraft onto a converging flight path so that the controller can sequence the aircraft for the runway more efficiently by maintaining minimum separation at the convergence point of the two flight paths.

Procedures

Surveillance over the oceans will improve with the implementation of the Automatic Dependent Surveillance (ADS) technologies which allow the aircraft to self-report position to other aircraft and the ground. Communications will improve as datalink technologies and Satellite Communications (SATCOM) are made available to aircraft and ATC. As the oceanic surveillance and communication improves to nearly match that of en route and TRACON capabilities, there could be a movement to reduce separation restrictions over the ocean. Air traffic authorities should strive to maintain consistency between the information support available to the controllers and the restrictions that the new procedures require them to meet.

Development of procedures also provides opportunity to develop the underlying air traffic structure. Consideration should be given to the types of structure manageable within human cognitive limitations, and how to take advantage of underlying structure that is cognitively unmanageable.

Supporting projection during integration of a decelerating approach procedure

One procedure being considered for the TRACON environment is a decelerating approach procedure that would reduce noise over communities below. However, this procedure also removes the ability of the controller to structure the airspeed of the aircraft within his or her sector through airspeed clearances.

It may be beneficial to take advantage of the structure that is present, namely the deceleration profiles of the aircraft. If the deceleration profile could be communicated to the controller and an effective behavioral discretization could be created between aircraft with discriminable deceleration profiles, projection may benefit. An example of a behavioral discretization between jets, regional jets, and turboprops based on deceleration profiles is shown in Figure 6. Projection would only benefit if the discriminable attribute (in this case whether the aircraft is a jet, regional jet, or turboprop) be communicated to the controller.

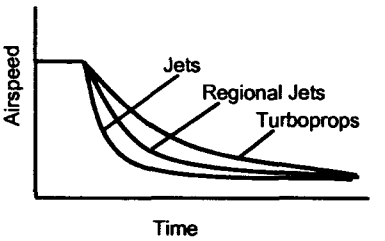

Figure 6: Notional deceleration profiles of 3 types of commercial aircraft.

If the controller is unable to internalize a behavioral model as subtle as a deceleration profile, system designers could take advantage of information support to aid the controller. If the aircraft follow a clear structure, such as a deceleration profile, a projection aid could perform the projection for the controller. This would allow the controller to take advantage of underlying traffic structure that would have been otherwise useless if the controller could not internalize the behavior to make a reliable projection.

CONCLUSIONS

An investigation into the ATC projection task of the TRACON and oceanic controller was made. Two key environmental characteristics influencing the type of projection made were separation requirements and surveillance/communication system performance. How the information was displayed also influenced whether projection was performed spatial-based or time-based. Structured traffic flow elements were mirrored in the interface to aid projection.

As technologies improve and procedures change, care should be taken by designers to support projection through displays, automation, and procedures. It is critical to prevent time/space mismatches between interfaces and restrictions. Existing structure in traffic dynamics could be utilized to provide controllers with useful behavioral models on which to build projections, or subtle structure could be incorporated into an ATC projection aid.

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